Simulated Physician Learning Program Improves Glucose Control in Adults With Diabetes

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OBJECTIVE — Inexpensive and standardized methods to deliver medical education to primary care physicians (PCPs) are desirable. Our objective was to assess the impact of an individualized simulated learning intervention on diabetes care provided by PCPs.

RESEARCH DESIGN AND METHODS — Eleven clinics with 41 consenting PCPs in a Minnesota medical group were randomized to receive or not receive the learning intervention. Each intervention PCP was assigned 12 simulated type 2 diabetes cases that took about 15 min each to complete. Cases were designed to remedy specific physician deficits found in their electronic medical record observed practice patterns. General linear mixed models that accommodated the cluster randomized study design were used to assess patient-level change from preintervention to 12-month postintervention of A1C, blood pressure, and LDL cholesterol. The relationship between the study arm and the total of intervention and patient health care costs was also analyzed.

RESULTS — Intervention clinic patients with baseline A1C ≥7% significantly improved glycemic control at the last postintervention A1C measurement, intervention effect of −0.19% mean A1C ($P = 0.034$) and +6.7% in A1C <7% goal achievement ($P = 0.0099$). Costs trended lower, with the cost per patient −$71 (SE = 142, $P = 0.63$) relative to nonintervention clinic patients. The intervention did not significantly improve blood pressure or LDL control. Models adjusting for age, sex, and comorbidity showed similar results. PCPs reported high satisfaction.

CONCLUSIONS — A brief individualized case-based simulated learning intervention for PCPs led to modest but significant glucose control improvement in adults with type 2 diabetes without increasing costs.

Diabetes Care 33:1727–1733, 2010

Although continuing medical education (CME) is required for physician licensure in many states, there is a paucity of evidence that traditional methods change physician behavior or improve clinical care (1). The Association of American Medical Colleges has called for increased study of CME approaches that incorporate adult learning principles, including tailored curricula and interactive experiences (e.g., simulated activities, self-directed learning, immediate feedback) (2). Of particular importance is emphasis on case-based context-dependent learning situations that address the complexity of specific clinical domains and focus on transfer of knowledge and skills beyond the specific learning situation (3). Personalized outreach visit approaches such as opinion leader interventions and academic detailing may influence some aspects of clinical care (4,5), including increased use of aspirin and β-blockers for acute myocardial infarction (5), antibiotic choices (6), and HIV prevention practices (7). However, associated drawbacks include costs, teaching nonuniformity, and difficulty finding quality opinion leaders in nonacademic settings.

Simulated case-based learning offers an efficient and less expensive personalized physician learning alternative. It has been successful in aviation and chemical engineering and is increasingly used in health care training programs (8,9) to teach Advanced Cardiac Life Support (8), various surgical skills (10), and airway management (11). Furthermore, our previously published evaluation of a brief prototype of the learning intervention used in this trial was encouraging (12). Therefore, development and rigorous evaluation of simulation approaches to teach the cognitive skills of chronic disease care management are warranted.

RESEARCH DESIGN AND METHODS

Hypothesis

This group-randomized trial was designed to test whether a personalized simulated learning intervention for physicians would improve care delivered to adults with uncontrolled diabetes.

Study setting, subjects, and design

The study was conducted from October 2006 to May 2007 at HealthPartners Medical Group (HPMG), a large medical group in Minnesota that serves about 230,000 patients. Eleven HPMG clinics were randomly selected and block randomized on the basis of baseline quality of diabetes care and number of consenting primary care physicians (PCPs) to either receive or not receive the intervention.

PCPs were eligible for the study if they practiced in one of the study clinics, provided care to at least 10 adult patients with diabetes, and signed a consent form. Patients were classified as having diabetes if they had two or more outpatient diabetes ICD-9 codes or used a diabetes-specific medication in the year before randomization (see Fig. 1 for the detailed consort description).

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Received 5 March 2010 and accepted 11 May 2010. DOI: 10.2337/dc10-0439. Clinical Trial Registry No.: NCT00979823; http://www.clinicaltrials.gov.

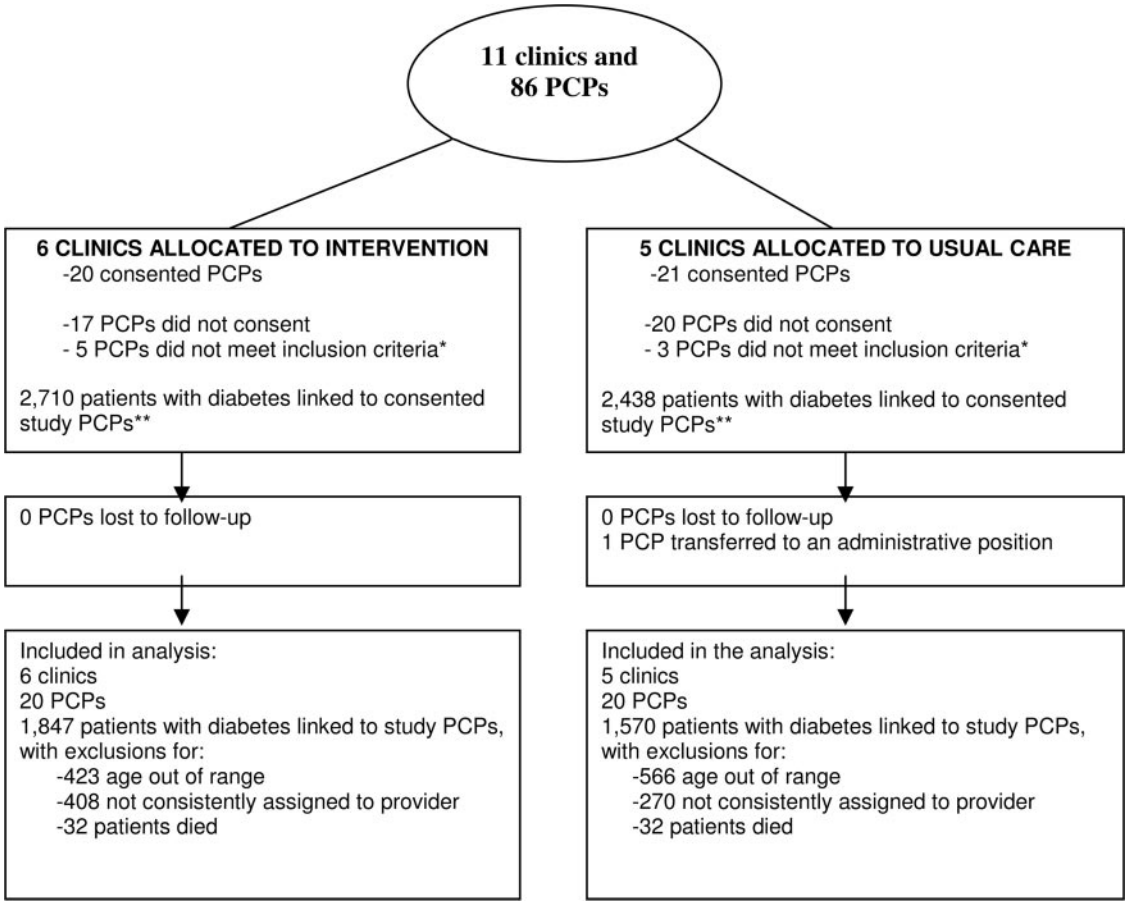

Figure 1—*Diagram illustrating allocation of clinics, PCPs, and diabetes patients to the two study arms. The diagram also shows the disposition of diabetes patients who were and were not included in the analysis. *Eligible PCPs worked >60% of a full time equivalent and had ≥10 patients with diabetes. **Patients were linked to the study-consented last-assigned PCP during the preintervention period and study-consented first-assigned PCP during the postintervention period. Patients lacking an assigned PCP were linked to the provider seen most during the study period. PCP, primary care physician.*

Intervention design

A group of PCP experts actively involved in diabetes guideline development identified and reached consensus on 25 essential clinical practices for the successful management of type 2 diabetes in adults (Table 1). The goal of the learning program was to promote mastery of these essential clinical practices.

The research team then used existing electronic medical record data to profile individual PCP performance on the essential clinical practices. If a physician performed below average compared with his or her physician peers on a clinical practice, a simulated case initialized with clinical parameters designed to teach the specific clinical practice was assigned.

Initialization parameters for the set of learning cases were defined to represent the wide range of complex clinical scenarios a PCP could encounter. Each case encompassed a different mix of baseline patient demographics (age, sex, duration of diabetes), medical history and comorbidities (congestive heart failure, renal insufficiency, coronary artery disease), pharmacologic use (active medications for glycemia, blood pressure [BP], lipids, depression, aspirin), clinical states (A1C, BP, lipid, creatinine, and self-monitoring of blood glucose results), and other subjective patient characteristics (hypoglycemia symptoms, medication adherence, lifestyle habits, and depressive symptoms). An automated case generator was developed to create distinct simulated learning cases.

A detailed description of the simulation software has been previously published (13). The patient model embedded in the software uses prespecified formulas derived from dose-response curves for drugs, lifestyle advice, and referrals. This allowed calculated changes in the patient state at each encounter on the basis of physician treatment actions. The interface mimics electronic medical record screens that permit the learner to prescribe drugs, order labs or diagnostic tests, make referrals, give patient advice, change frequency of recommended self-monitoring of blood glucose testing, view self-monitoring of blood glucose results, start or adjust insulin with each meal and at bedtime, and see the patient at any desired frequency for phone or office visits.

A key strategy of the learning intervention was the individualization embedded in the intervention at multiple levels. First, the PCPs received a customized set of simulated cases selected to address their assessed learning needs. Second, feedback resulted from a multitude of individual provider actions, yielding a unique trajectory to each case in response to the learner's specific treatment decisions. Learning feedback occurred through seeing the clinical effects of treatment moves at subsequent encounters, seeing graphic displays of the projected results of accumulated treatment actions, and direct textual feedback after each encounter consisting of a critique of past actions and suggestions for future ones.

Table 1—*The 25 essential clinical care practices taught in the simulated program*

	Glycemia practice	Hypertension practice	Lipid practice
1	Early drug initiation after medical nutrition therapy failure	Initiation of BP medication, new diagnosis	Initiation of statin above goal
2	Initiation of additional oral drugs or exenatide beyond metformin and sulfonylureas	Appropriate use of home BP measurements	Use of fibrate for high triglyceride
3	Initiation of insulin or exenatide	Initiation of combo drugs for stage 2 hypertension	Use of fibrate for low HDL
4	Change to updated insulin regimen (basal bolus insulin regimens)	Adding drug classes as needed	Titrating statin or ezetimbe to achieve LDL goals
5	Initiation of metformin as insulin sensitizer	Initiation of fourth drug class	Titrating lipid drugs, fear of myalgias
6	Initiation of thiazolidinedione as insulin sensitizer	Titration of drugs	Reassessing lipids ≤3 months after adjusting lipid medications
7	Initiation of prandial insulin	Target systolic BP	Yearly monitoring of lipids
8	Titration of basal insulin	Importance of treatment in the elderly	Monitoring liver enzymes tests
9	Titration of prandial insulin	More frequent visit intervals for patients not at goal	
10	Titration of insulin in large enough amounts	Monitoring potassium and creatinine after starting or increasing an ACE inhibitor or angiotensin receptor blocker	
11	Use of SMBGs and pattern recognition	Use of ACE inhibitor or angiotensin receptor blocker for congestive heart failure	
12	Optimal metformin dosing		
13	Optimal sulfonylurea dosing		
14	Optimal insulin dosing		
15	Optimal thiazolidinedione dosing		
16	Timely visit intervals		
17	Avoid severe hypoglycemia (<60 mg/dl)		
18	Address mild hypoglycemia (60–69 mg/dl)		
19	Avoid fear of low normal glucose levels (70–89 mg/dl)		
20	A1C frequency ≤3 months if not at goal		
21	A1C frequency ≤6 months at goal		
22	Metformin/creatinine contraindications		
23	Metformin/heart failure warnings		
24	Thiazolidinedione/heart failure warnings		
25	Educator referrals for patients not at goal		

MNT, medical nutrition therapy; TZD, thiazolidinedione; HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol; SMBG, self-monitored blood glucose; ACE, angiotensin-converting enzyme inhibitor; ARB, angiotensin-receptor blocker; TG, triglyceride.

Intervention implementation

PCPs were sent an email link to the program, accessed through a secure login page housed on an internal server. Clicking on the name of one of the 12 assigned cases started the simulation. The physician was challenged to achieve the American Diabetes Association–recommended treatment goals for BP, lipids, and A1C within 6 months of simulated time. Each case took about 15 min to complete.

Physicians received financial compensation ($600) and up to 6 h of CME credit for completing the program, which had to be done on their own time. The average number of days to complete the 12 cases was 5.5. At the end of the intervention, physicians also were sent an evaluation of the learning program.

Dependent variables

Measures of intermediate outcomes (A1C, BP, LDL levels) of diabetes care in patients of providers extracted from the electronic medical record were the principal dependent variables. The baseline measurements were the clinical values viewable by the provider at the first encounter after completing the learning intervention. For A1C and LDL, this was the last clinical value obtained in the 1-year preintervention period. Because of point-of-care availability of blood pressure levels at encounters, the baseline measurement for BP was the first value in the 1-year postintervention period. For all measures, the last value in the postintervention period is selected as the post-intervention variable. No changes in laboratory assay methods occurred during the study.

Costs were estimated from the health plan perspective and included the costs of the intervention and health care costs. Intervention costs included *1*) marketing to physicians; *2*) profiling physician learning needs; *3*) implementing physician training, case assignment, and email reminders; and *4*) physician compensation for completing cases. Health care costs included outpatient services and pharmaceuticals. Inpatient services were not included because the intervention was not expected to affect hospitalization rates. Costs were estimated using methods previously developed to assign costs of services in this medical setting (14). Services were based on relative value

units assigned on the basis of procedure codes recorded and priced at the 2009 physician services conversion factor of $36.07. Costs of pharmaceuticals were based on 68% of the average 2009 wholesale price.

Independent variables

The independent variable was an indicator for study arm. The interaction of this with time was used to assess the differential impact of the intervention on the prespecified outcomes. Because the trial was group-randomized at the clinic level, imbalance in patient characteristics was expected. Patient-level independent variables include age, sex, race, and validated indicator variables for coronary artery disease and congestive heart failure. Adults older than 80 years and individuals with Charlson comorbidity scores of ≥3 (indicating high short-term risk of mortality) were excluded from the study because of legitimate debate about appropriate clinical goals in such scenarios (15).

Statistical analysis

Attributes of study-consented physicians and patients linked to these physicians are compared by study arm using descriptive statistics (mean, SD, proportions) and using independent sample *t* tests, contingency tables, and Pearson χ^2 tests.

General and generalized linear mixed models with a repeated time measurement (baseline and postintervention) were used to analyze continuous and binary outcomes using SAS Proc Mixed and Proc Glimmix. These models included a term for study arm, time (baseline or postintervention), a time by study arm interaction term, and random intercepts to account for multiple levels of nesting. The time-by-study-arm interaction term tested the effect of the intervention arm over time relative to the effect of the control arm over time. The analyses on test values were also conducted predicting postintervention values from study arm, preintervention test value, and patient covariates.

Denominators for the analysis of test rates, encounter rates, and numbers of tests and encounters include all (n = 3,417) eligible patients linked to study-consenting physicians. Analyses for change in values (e.g., A1C) are based on subsets of patients who are not at goal at baseline on particular measures of interest, because they are targeted in the intervention. A priori sample size calculations assumed an analytic sample of 500 diabetic patients per study arm, based on 20 providers with 25 diabetic patients not at A1C goal. Effective patient sample size was estimated as n = 291 per arm due to clustering of patients within physicians (estimated intraclass correlation [ICC] = 0.03). This study was designed with 80% power to detect an A1C difference of 0.3% between study arms, with a two-tailed α = 0.05. Alpha levels are not adjusted for testing of multiple dependent variables.

Generalized linear models, assuming γ distribution and a log link function, were used to analyze the relationship between costs and study arm (16). These models included a term for study arm, time (baseline or postintervention), and a time-by-study-arm interaction term. A standardized estimate of the effect of the intervention on costs was calculated as a mean difference in predicted costs among study patients (including all patients with A1C >7% in the preintervention period), as they were alternatively assigned to the intervention and control groups in the post period. SEs were estimated using the nonparametric bootstrap, and significance values were computed using the percentile method (17).

Table 2—*Characteristics of study physicians and diabetes patients linked to those study physicians at intervention and control clinics*

	Intervention clinics	Control clinics	*P**
Patients (*n*)	1,847	1,570	
Age (years)	55.9 ± 10.9	56.9 ± 10.4	0.012
Female (%)	44.6	54.0	<0.001
White race (%)	72.2	69.1	0.054
Coronary artery disease during preintervention (%)	11.3	11.3	0.97
Congestive heart failure during preintervention (%)	3.4	4.0	0.35
Preintervention first A1C value	7.4 ± 1.7	7.5 ± 1.7	0.18
Median	7.0	7.1	
Preintervention first SBP value	126.7 ± 17.7	125.8 ± 16.8	0.12
Median	125	124	
Preintervention first DBP value	74.0 ± 10.9	73.4 ± 10.6	0.12
Median	73	74	
Preintervention first LDL value	95.7 ± 34.1	96.5 ± 34.5	0.53
Median	92	91	
PCPs (*n*)	20	20	
Age (years)	48.5 ± 7.9	50.2 ± 7.3	0.51
Family practice physicians (%)	45.0	45.0	0.99
Female (%)	40.0	50.0	0.53
Number of adult diabetes patients per PCP	57.0 ± 28.7	55.8 ± 30.2	0.90

Data are means ± SD unless otherwise indicated. *Independent samples *t* test or Pearson χ^2. CHF, congestive heart failure; LDL, low-density lipoprotein cholesterol; PCP, primary care physician; DBP, diastolic blood pressure; SBP, systolic blood pressure.

Protection of human study subjects

The study was reviewed in advance, approved, and monitored on an ongoing basis by the HealthPartners Institutional Review Board, Project #03-083.

RESULTS — Attributes of study-eligible patients and PCPs are presented in Table 2. Diabetic patients' age was 56.4 ± 10.7 years (mean ± SD), 24.0% were 65–74 years old, 48.9% were female, and 29.2% were nonwhite. At baseline (first preintervention value), 47.5% had A1C <7%, 61.7% had systolic BP (SBP) <130 mmHg, 67.3% had diastolic BP (DBP) <80 mmHg, and 60.2% had LDL <100 mg/dl. The number of diabetic patients per study-enrolled PCP ranged from 10 to 125, with a mean of 56.4 ± 29.1. Randomization at the clinic level resulted in an intervention arm with a higher proportion of younger and male patients.

In four-level random intercept models (measurement occasion nested within patient, provider, and clinic), ICCs at the clinic level were generally small, with values of ICC <0.0001 for A1C and LDL value, ICC = 0.001 for SBP value, and ICC = 0.003 for DBP. Because of the low level of variance at the clinic level, three-

Table 3—*Rates and counts of diabetes encounters, A1C tests, cholesterol tests, BP measurements, and changes in A1C, BP, and LDL control in adult diabetes patients of intervention and control group PCPs in the pre- and postintervention periods*

	Intervention clinics			Control clinics			Intervention effect[a]	P ($t \times c$)[b]
	Baseline	Postintervention	Change	Baseline	Postintervention	Change		
Proportion (95% CI) of patients with one or more encounters or tests (n = 3,417)								
Diabetes encounters	0.889 (0.866–0.908)	0.946 (0.931–0.958)	+0.057*	0.886 (0.861–0.907)	0.933 (0.915–0.947)	+0.047*	+0.010	0.27
A1C test	0.858 (0.827–0.884)	0.907 (0.884–0.926)	+0.049*	0.872 (0.842–0.897)	0.906 (0.882–0.926)	+0.034†	+0.015	0.41
BP obtained	0.992 (0.986–0.995)	0.985 (0.978–0.990)	−0.007	0.985 (0.978–0.990)	0.986 (0.979–0.991)	+0.001	−0.008	0.13
LDL test	0.849 (0.819–0.875)	0.886 (0.861–0.907)	+0.037†	0.833 (0.801–0.862)	0.854 (0.824–0.880)	+0.021	+0.016	0.22
Mean (95% CI) of number of encounters or tests per patient (n = 3,417)								
Number of diabetes encounters	4.1 (3.7–4.5)	4.3 (3.8–4.7)	+0.16	4.5 (4.1–4.9)	4.8 (4.4–5.2)	+0.31‡	−0.15	0.39
Number of A1C test	1.9 (1.7–2.0)	2.1 (2.0–2.3)	+0.24*	2.1 (1.9–2.2)	2.2 (2.1–2.4)	+0.14†	+0.09	0.12
Number of LDL tests	1.5 (1.4–1.6)	1.6 (1.5–1.8)	+0.13†	1.5 (1.3–1.6)	1.5 (1.3–1.6)	+0.02	+0.11	0.07
Mean (95% CI) of test values and proportion (95% CI) at goal[c]								
A1C	8.4 (8.3–8.6)	7.9 (7.7–8.1)	−0.53*	8.4 (8.3–8.6)	8.1 (7.9–8.3)	−0.33*	−0.19	0.034
A1C <7%		0.292 (0.257–0.329)			0.225 (0.193–0.261)			0.009
SBP (mmHg)	138.9 (137.2–140.7)	130.9 (129.1–132.6)	−8.1*	139.5 (137.7–141.3)	131.3 (129.5–133.2)	−8.2*	+0.06	0.965
SBP <130 mmHg		0.502 (0.446–0.558)			0.529 (0.470–0.587)			0.509
DBP (mmHg)	80.2 (79.0–81.3)	75.5 (74.3–76.7)	−4.6*	80.2 (78.9–81.5)	76.4 (75.2–77.7)	−3.8†	−0.9	0.257
DBP <80 (mmHg)		0.606 (0.545–0.663)			0.590 (0.526–0.651)			0.714
LDL (mg/dl)	122.0 (119.1–125.0)	103.8 (100.7–106.8)	−18.3*	123.6 (120.4–126.8)	100.3 (96.9–103.7)	−23.3*	+5.1	0.039
LDL <100 mg/dl or <70 mg/dl with CHD		0.413 (0.363–0.466)			0.414 (0.359–0.470)			0.998

‡$P < 0.05$; †$P < 0.01$; *$P < 0.001$. [a]The intervention effect column illustrates the differential amount of change in the intervention arm relative to the control arm comparing pre- to postintervention. [b]P value associated with the time × condition term in a generalized linear mixed model with repeated time measurements, study arm, and their interaction. [c]For A1C and LDL test values, baseline is the last preintervention value. For SBP and DBP, baseline is the first postintervention test. For all test values, follow-up is the last postintervention value. Separate test value analyses consists of those with baseline A1C ≥7 (n = 1,403). SBP ≥130 and/or DBP ≥80 at the last preintervention test and first postintervention test (n = 920), LDL ≥100 (>70 for CHD patients) (n = 1,069). BP, blood pressure; DBP, diastolic blood pressure; SBP, systolic blood pressure; LDL, low-density lipoprotein cholesterol; CHD, coronary heart disease.

level models are presented by dropping the random intercept term for clinic.

Table 3 shows baseline and follow-up measures of diabetes encounters, A1C, BP, and LDL test rates. They increased between pre- and postintervention measurements, with no differential effect for the intervention group, as shown by the nonsignificant time-by-condition interaction term *P* values.

Statistically significant improvements over time were seen within study arm for A1C, SBP, DBP, and LDL values. Intervention-arm patients had a significantly greater improvement (decrease) in A1C value from baseline to postintervention than the control arm by a value of −0.19% (95% CI −0.37 to −0.01, $P = 0.034$). Among patients with an A1C ≥7% at the last preintervention measurement, 29.2% of intervention-arm and 22.5% of control-arm patients had an A1C <7% at the last postintervention measurement ($P = 0.0099$, $n = 1{,}403$). There were no significant differences in SBP or DBP reduction over time by study arm. Control-arm patients had a significantly greater improvement (decrease) in LDL value from baseline to postintervention than the intervention arm by a value of −5.1 mg/dl (95% CI −9.8 to −0.3, $P = 0.039$). Analysis of the proportion of patients at LDL goal (<100 or <70 mg/dl with coronary artery disease) at the last measurement in the 12-month postintervention period showed no significant difference (0.413 intervention clinics, 0.414 control clinics, $P = 0.99$, $n = 1{,}069$).

Intervention costs were estimated to be $27 per patient. Total costs, including intervention and health care costs, were estimated to be $71 (SE = 142, $P = 0.63$) lower per patient in the intervention clinics compared with control clinics.

A total of 85% of intervention PCPs completed a survey of satisfaction and self-assessed impact of the learning. Of these, 88% would recommend the learning experience to other physicians, 82% thought it would help most doctors improve their diabetes care skills, 82% reported they would be more likely to intensify medication for their diabetic patients, 59% would shorten their visit intervals, and 18% would start insulin more often. A separate analysis showed that preintervention PCP performance measured by the percentage of patients at glycemic goal was not a significant predictor of A1C postintervention ($P = 0.98$).

CONCLUSIONS — This personalized physician learning intervention demonstrated a modest but significant A1C lowering without increasing patient visits or total net costs. The observed A1C impact (a 0.5% improvement in A1C in the intervention group, which was 0.19% better than the control group) is of roughly the same magnitude as that reported in uncontrolled observational studies of more expensive interventions intended to improve diabetes care, such as clinical information systems (18), patient education, and disease management programs (19). The net A1C improvement is clinically significant based on the potential to reduce patient complications, as demonstrated through UK Prospective Diabetes Study results showing 37% lower microvascular complications for every 1% absolute A1C reduction (20).

PCPs reported high levels of satisfaction with the intervention, repeated learning cases voluntarily, and reported tangible changes in the way they manage diabetes. The learning effect of the computer-based intervention was present independent of PCP baseline diabetes performance and indicates an ability to transfer what was learned from the simulated cases to the care of real patients—an important challenge and desirable finding in simulation research.

There are a number of points to make about the cost of this intervention in relation to its modest clinical effectiveness. First, the intervention did not increase patient visits or testing rates in real patients and trended toward cost-saving. Second, this simulated approach to physician learning is compatible with a wide range of chronic care improvement activities designed to activate patients or develop prepared care teams (21). Finally, the simulation content can be easily adapted to accommodate changes in care guidelines, discourage unnecessary tests or treatments, and encourage use of generics and might help modulate to some degree the high costs of diabetes care. The marginal costs for ongoing use of this learning tool are relatively small and principally involve periodic updates to ensure that the simulation model remains current with evidence-based treatment strategies and newly approved drugs.

Future research should investigate issues that might increase the impact, reduce the complexity, or broaden the dissemination potential of the intervention. Our use of electronic medical record–based physician treatment patterns to assess learning needs is innovative but can be difficult. Development of simpler methods to evaluate physician learning needs (e.g., assessment on a set of prespecified simulated cases) warrants investigation. Second, the intervention needs adaptation for web distribution and to simplify addition of clinical updates when needed. Third, at the time of this study, generalized diabetes care goals, such as A1C of <7%, were widely accepted. As personalized medicine seeks to accommodate individualized treatment goals, this approach provides an opportunity to teach a systematic approach to setting clinical care goals individualized to patient characteristics such as comorbidities, polypharmacy concerns, hypoglycemia risk, and genetics (22,23).

Additional work is needed to elucidate more precisely the mechanisms responsible for the observed effects. The variable effect on clinical domains may be partially related to primary emphasis on glucose-related feedback in the learning cases relative to BP or lipid-related feedback. Recent clinical trial results (23,24) highlight the importance of directing more attention to BP- and lipid-management issues. It is notable that the study site had relatively good baseline levels of A1C, BP, and LDL (25). The impact of this learning intervention in settings with worse baseline levels of diabetes care remains to be determined. This promising care-improvement strategy might also be applied to other clinical domains.

Despite some limitations, these data demonstrate that delivery of a brief and relatively inexpensive individualized physician learning intervention improved intermediate outcomes of diabetes care without increasing costs. Experimentation with simulated personalized learning interventions in a broad range of other care or educational settings seems warranted.

Acknowledgments— This project was funded by NIDDK Grant #R01 DK068314 to HealthPartners Research Foundation.

J.M.S.-H. received support indirectly through HealthPartners Research Foundation for multisite drug trials funded by Merck, GlaxoSmithKline, and Abbott Pharmaceuticals and from Merck for a randomized trial on educational methods for patients with diabetes. H.L.E. owns stock in Pfizer. No other potential conflicts of interest relevant to this article were reported.

J.M.S.-H., P.J.O., P.E.J., T.G., and S.E.A. contributed to writing the manuscript. J.M.S.-H., P.J.O., W.A.R., P.E.J., T.G., S.E.A., and H.L.E. contributed to the review and editing of this manuscript.

An abstract of the main results of this study was presented at the 2010 American Diabetes Association Scientific Sessions.

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